THE EFFECTS OF AGE ON WITHIN-TRIAL MODULATION OF COGNITIVE CONTROL

A Thesis
Presented to
The Academic Faculty

By

Thomas G. Hutcheon

In Partial Fulfillment
of the Requirements for the Degree
Masters of Science
School of Psychology

Georgia Institute of Technology
December, 2010

THE EFFECTS OF AGE ON WITHIN-TRIAL MODULATION OF COGNITIVE CONTROL

Approved by:

Dr. Daniel H. Spieler, Advisor
School of Psychology
Georgia Institute of Technology

Dr. Eric H. Schumacher
School of Psychology
Georgia Institute of Technology

Dr. Paul Verhaeghen
School of Psychology
Georgia Institute of Technology

Date Approved: April 9, 2010

ACKNOWLEDGMENTS

Thanks to the participants who gave of their time, my family and my friends, and my advisor, Dr. Dan Spieler. I would also like to thank Mer for all of her love and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Cognitive control allows us to function in a world filled with constant stimulation. For example, the act of reading a book requires the ability to inhibit irrelevant information while focusing attention towards the letters on the page. Our cognitive control system regulates what information receives attention and what is denied resources. The goal of the current paper is to investigate the mechanisms underlying the activation and maintenance of the control system and how this process changes in healthy aging. First, the ability of younger and older adults to activate and maintain control in response to trial type manipulations is investigated. Second, improvements are made to recent experimental evidence suggesting younger adults are able to modulate performance based on specific stimulus history. Third, this work is extended to an older population suggesting the ability to modulate performance based on specific stimulus history is maintained in healthy aging. Finally, it is demonstrated that current theories of control fail to account for age-related differences in performance based on the comparison of trial type and specific stimulus manipulations.

CHAPTER 1

INTRODUCTION

Interference laden selective attention tasks such as the Stroop (MacLeod, 1991) and flanker tasks (Eriksen & Eriksen, 1974) are often used to study cognitive control. These tasks require participants to attend to a relevant stimulus dimension while inhibiting information from an irrelevant dimension. The irrelevant dimension may provide information consistent (congruent trial) or inconsistent (incongruent trial) with the correct response. The influence of the irrelevant dimension is measured by comparing the incongruent condition to either the congruent condition (congruency effect) or a neutral condition (interference effect) [1]. Individuals or groups with less effective control should show greater influence of the irrelevant dimension and therefore a larger congruency effect. In fact, larger congruency effects have been found relative to controls in a number of groups believed to have deficits in control processing such as older adults (Cohn, Dustman, & Bradford, 1984), individuals with low working memory capacity (Kane & Engle, 2003; Kimberg & Farah, 1993), and those suffering from major depression (Moritz et al., 2002; Peterson et al., 1999). Here, I focus on the age-related changes in Stroop performance and what this indicates about the effectiveness of control processes in healthy aging (Cohn, et al., 1984; Spieler, Balota, & Faust, 1996; West, 1996; but see Verhaeghen & De Meersman, 1998).

---

[1] While the selection of appropriate neutral conditions does allow one to separate facilitation and interference effects, for the present paper, I will focus on the combination of facilitation and interference by looking at congruency effects (Macleod, 1991).

There are a variety of manipulations of stimulus parameters that influence the congruency effect in interference tasks (see Macleod, 1991 for review). For example, manipulations may influence the difficulty of selection on a specific trial by degrading the quality of the relevant information. In a Stroop task, decreasing the quality of information from the color dimension by varying the hue intensities makes color naming more difficult and increases the congruency effect (Lindsay & Jacoby, 1994). In the present paper, another influence on the congruency effect is investigated. Specifically, in *list level* manipulations, when trials are presented within a context of a high proportion of congruent trials, the congruency effect is larger relative to when trials are presented in the context of a high proportion of incongruent trials in both the Stroop (Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Tzelgov, Henik, & Berger, 1992; West & Baylis, 1998), and flanker tasks[2] (Gratton, Coles, & Donchin, 1992; Ullsperger, Bylsma, & Botvinick, 2005). Shown in Figure 1 are the congruency effects for a number of studies that manipulate the list level condition proportions in the Stroop task.

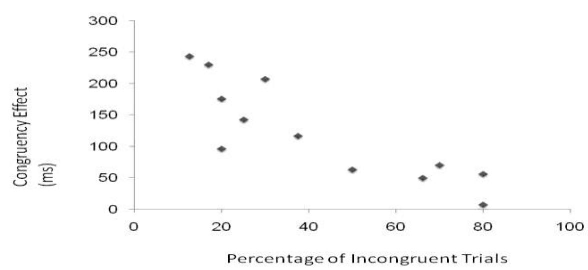

Figure 1. Reported congruency effects for younger adults based on the percentage of incongruent trials in a Stroop color naming paradigm (Tzelgov et al., 1992; Logan et al., 1984; Logan & Zbrodoff, 1984; West & Baylis, 1998; Mutter et al., 2005)

[2] For the purposes of this paper, list level manipulations in which over 65% of trials are congruent will be referred to as mostly congruent. Manipulations in which over 65% of trials are incongruent will be referred to as mostly incongruent.

One explanation for the list level modulation of the congruency effect is it reflects adjustments in the use of the word and color dimensions (Cheesman, & Merikle, 1986). When the majority of trials are congruent, the irrelevant dimension often carries information that is consistent with the correct response. Because word information is easily processed (MacLeod, 1991), it may be adaptive to loosen control to allow in information from the nominally unattended word dimension. A reduction in the inhibition of the irrelevant dimension allows for faster performance on congruent trials, slower performance on incongruent trials, and results in a large congruency effect. Contrast this with a block of mostly incongruent trials. In this case, the irrelevant dimension will often carry information that is inconsistent with the correct response. Thus, it may be adaptive to tighten control to further inhibit the word dimension. Increased inhibition of the word dimension leads to slower congruent trials, faster incongruent trials, and a smaller congruency effect compared to a mostly congruent list.

The influence of condition proportions could come from a strategic adjustment in the use of word information. However, individuals do not require explicit instruction about the condition proportions to exhibit the effect (Logan & Zbrodoff, 1979; Logan, et al., 1984; Tzelgov, et al., 1992) and when later asked, have no explicit knowledge of the manipulation (Crump, Gong, & Milliken, 2006). While extreme manipulations of condition proportions may not require explicit instruction for individuals to become aware of the potential usefulness of the word dimension, the relatively smooth increase in the congruency effect with increasing proportion congruent (Figure 1) suggests a more subtle and continuous variation of inhibition. In particular, the effect of condition proportion seems to arise from the cumulative effect of individual trials over the course of the experiment.

List level condition proportion results may arise from trial to trial mechanisms based on the observation that the congruency effect on trial *n* is reduced if trial *n-1* is incongruent compared to congruent. The change in the congruency effect as a function of the condition of the prior trial is referred to as the conflict adaptation effect (Nieuwenhuis et al., 2006; Vanderhasselt, De Raedt, & Baeken, 2009). This term suggests that the presence of conflicting information on the prior trial leads to changes in current trial processing, resulting in a reduction in the use of the distracting information. Thus, this will lead to less facilitation when the current trial is congruent and less interference when the current trial is incongruent. This effect is present in a variety of selective attention tasks such as the flanker (Botvinick et al., 2004; Egner, 2007; Egner & Hirsch, 2005; Gratton et al., 1992), Simon (Hommel, Proctor, & Vu, 2004; Wendt, Kluwe, & Peters, 2006), and Stroop tasks (Botvinick et al., 2004; Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006, but see Mayr, Awh, & Laurey, 2003).

One explanation for this sequential variation in the congruency effect is that the presence of conflict initiates a feedback signal that acts to engage or strengthen processes that lead to the suppression of the pathways carrying irrelevant information and activation of the pathways carrying the relevant information sources (Botvinick, Braver, Barch, Carter, & Cohen, 2001). For the purpose of the current paper, the conflict monitoring theory provides a mechanistic framework for understanding age differences in the influence of condition proportions.

Conflict Monitoring Theory

Connectionist models of interference tasks view the role of cognitive control as modulating the flow of information along pathways carrying information from different stimulus dimensions (Botvinick et al., 2001; Cohen, Dunbar, & McClelland, 1990). The control signal originates in a representation of the task as a distribution of activation across a set of units and these units act to turn up or down the gain of activation on units along the various pathways. Within these models, conflict monitoring is accomplished by the addition of a feedback loop between the response units and the units representing the task. This feedback loop takes information about the presence of conflict at the response level, operationalized as the simultaneous activation of multiple response units, and increases the activation of the task representation in response to conflict. Similarly, the feedback loop decreases activation of the task representation in the absence of conflict[3]. Such variations in the activation of task units in turn results in modulation of information flow from the different stimulus dimensions. The result is that compared to low conflict trials, high conflict trials set up the system for more efficient selection on the subsequent trial. This suggests that the nature of the sequential effect is a joint reflection of the maintenance of the task set representations and the conflict signal (Botvinick et al., 2001).

The joint interaction between conflict and task set representation has some support from findings that frontal regions of the brain are jointly and sequentially activated during performance of these interference tasks. Dorsal Anterior Cingulate Cortex (dACC) is activated in a variety of tasks when competing responses are present (Carter et al., 1998; Dehaene, Posner, & Tucker, 1994; Holroyd et al., 2004; Miltner et

[3] In selective attention tasks, conflict occurs in the form of incongruent trials. Computationally, activation of control serves to make units carrying “color” information more sensitive to input and units carrying “word” information less sensitive.

al., 2003). In some cases, the activation of dACC precedes activation of the dorsal lateral prefrontal cortex (DLPFC), an area important in the representation of behavioral goals and task sets. Interestingly, larger behavioral adjustments in control were observed following high levels of activation in the ACC when activation of the ACC was associated with increased activation in the DLPFC on the subsequent trial (Kerns et al., 2004). Overall, the conflict monitoring framework provides a relatively simple set of mechanisms that account for the behavioral effects and identifies a plausible set of neural structures involved in these processes.

Conflict Monitoring Theory and Aging

Of interest to the present paper, the two interacting mechanisms in a conflict monitoring framework appear to be influenced by age. For example, the age-related increase of the congruency effect generally observed in older adults (Cohn et al., 1984; West, 1996) may be due to age-related deficits of control processes, specifically deficits in maintenance of task-set representations (Braver et al., 2001; Paxton, Barch, Racine, & Braver, 2008). According to a conflict monitoring model, weaker task set representation leads to increased conflict and a larger feedback signal to increase activation of the task set, and in turn leads to increased modulation of processing pathways on the following trial (Botvinick et al., 2001). If older adults have difficulty in maintaining a consistently active task set representation, they may be more dependent on the presence of conflict and the resultant feedback to maintain performance. Thus, the prediction is that the conflict adaptation effect should be larger for older adults compared to younger adults. To date, the evidence is mixed. In two studies, numerically larger conflict adaptation effects were obtained for older adults compared to younger adults, though both studies failed to obtain statistically significant age-differences (Hutcheon, unpublished data; West & Moore, 2005). More suggestively, using event related potentiations (ERPs), older and younger adults were differentiated by the absence of a frontal slow wave in response to congruent and incongruent trials in older adults (West & Moore, 2005).

The control monitoring account argues list level effects are sequential effects aggregated over a number of trials. Thus, age-related differences in the processes underlying conflict adaptation effects (see West & Moore, 2005) suggest larger effects of list level condition proportions in older compared to younger adults. Consistent with age-related conflict adaptation interpretations (Mutter, Naylor, & Patterson, 2005; West & Moore, 2005), older adults did show numerically larger fluctuations in the congruency effects between the mostly congruent and mostly incongruent list types, taken to reflect age-related differences in processing, but again this interaction failed to reach significance (West & Baylis, 1998). However, the appeal of the conflict monitoring account for understanding age differences is also in the putative neural mechanisms that are believed involved in this account.

The DLPFC and the ACC are differentially influenced by aging. Investigations into the neural mechanisms underlying control in aging point to dysfunction in regions associated with task-set maintenance for two reasons. First, structural properties of the PFC appear to be especially susceptible to healthy aging (Hedden & Gabrieli, 2004; West, 1996). Second, overall activation of the PFC appears to decrease in selective attention tasks with age (Milham et al., 2002; Miller & Cohen, 2001; Raz, 2005). Despite deficits in the integrity of the PFC and task-set maintenance, there is evidence that ACC activation in response to conflict on the prior trial is maintained and possibly increases in healthy aging (Nessler, Friedman, Johnson, & Bersick, 2006). For example, in one study, not only was there an increase in ACC activity found in older adults relative to younger adults, but conflicting trials more reliably activated the ACC in older adults (Milham et al., 2002).

Overall, one would have to characterize the evidence for age differences in conflict monitoring as more suggestive than definitive. One potential difficulty is that the focus on conflict signals may be a relatively impoverished view of the sources of information individuals use while performing selective attention tasks. It is clear that in some cases, conflict may convey information and individuals are capable of using this information. In the next section, I turn to a set of results that suggest adjustments in performance can be made based on specific item associations.

Item-Specific Effects of Control

The theoretical account for list level and sequential variations in the congruency effect suggests that selectivity is influenced by the experience of conflict that acts via feedback signal to task set representations and that, in turn, modify selectivity on subsequent trials (Botvinick et al., 2001). Here, conflict is divorced from the specific combination of stimulus attributes. A seemingly contradictory finding to the conflict monitoring account of list level effects is that modulations in the congruency effect can be observed in the absence of condition proportion manipulations (Jacoby, Lindsay, & Hessels, 2003).

In the same way the proportion of congruent and incongruent trials can be adjusted in a list level manipulation, the proportion of times a given word appears as a congruent or incongruent stimulus can also be altered. For example, within a context in which there are an equal proportion of congruent and incongruent trials, the word RED is presented in the color blue 75% of the time. On the remaining 25% of RED trials the word RED is presented in the color red. In this case, the word RED appears in a mostly incongruent condition. Within the same experiment, a similar list can be generated to constitute a mostly congruent condition. For example, the word GREEN presented in the color green 75% of the time and presented in the color black 25% of the time. This type of manipulation is referred to as an *item level* manipulation. Importantly, because this can be done within-subjects, an equal proportion of trial type (congruent versus incongruent) can be maintained at the list level. In total, 50% of all trials are congruent and 50% of all trials are incongruent, however, specific words appear in either mostly congruent or mostly incongruent item level conditions (Jacoby et al., 2003). The results of item specific manipulations are similar to the effects observed in list level manipulations. That is, the congruency effect for the mostly congruent items is larger than that for the mostly incongruent items. This Item Specific Proportion Congruence (ISPC) effect suggests that the history of a specific word provides information with regards to the likely response on the current trial (Jacoby, et al., 2003; Jacoby, McElree, & Trainham, 1999).

The principle difficulty the ISPC effect presents to the conflict monitoring account is in the focus on the sequential influence of conflict on control. That is, in the conflict monitoring account, from one trial to the next, the sequential influence of the previous condition and the cumulative effect of a list level proportion is in the presence of conflict rather than the specific associations between words and colors. Because the overall proportion of congruent and incongruent trial is held constant, then across the mostly congruent and incongruent items, there is no difference in the probability of the prior trial condition and hence conflict monitoring predicts no difference between these items. That such item level effects might be present is not particularly surprising. Individuals are often very sensitive to the frequency and correlations in the environment (Dishon-Berkovits, & Algom, 2000; Melara & Algom, 2003, Miller, 1987). The question is what are the implications for such effects on the notion of sequential control in the conflict monitoring framework?

It has been noted combining lists from a mostly incongruent list level manipulation with the mostly congruent list level manipulation results in an item level manipulation. Thus, parsimony might suggest that the list level effects are entirely subsumed by an account of the item level effects. An item level model of control has been proposed to explain list level and item level effects based on associations that build up between the color and word dimension (Blais, Robidoux, Risko, & Besner 2007). The item level control account maintains the structure of the conflict monitoring model, but differs on the information carried by the conflict signal. For example, in the mostly incongruent condition of an item level manipulation the word BLUE presented in the color green on trial *n-1* would lead to tightening of control only for a stimulus containing the word BLUE or color green on trial *n*. Therefore, conflict adaptation effects are based on specific word and response associations, not general conflict. In this way, control is exerted not at the task set but of the specific item level. Here, we have competing explanations for the list level effects; the conflict monitoring account (Botvinick et al., 2001) and the item level control account (Blais et al., 2007; Jacoby et al, 2003). If it is the case that there is a single mechanism underlying both the item and list level effects, then age-related results for list level manipulations should parallel age-related results for item level manipulations.

There are three aims to the current set of experiments. In Experiment 1, within a list level manipulation framework, I examine the general influence of condition proportions on the performance of younger and older adults. In Experiment 2, I implement a manipulation that serves to dilute some of the contributions of stimulus-response repetitions researchers have suggested artificially impacted the original ISPC results (Risko, Blais, Stoltz, & Besner, 2008; Blais et al., 2007). Finally, I ask whether the contribution of item associations influence the performance of young and older adults differentially and examine the results in terms of a fit with the item level control model.

CHAPTER 2

EXPERIMENT 1

Experiment 1 serves as an empirical replication of West and Baylis (1998). While age differences in response to list level proportions is commonly noted in the literature (e.g. Mutter, et al., 2005; West & Alain, 2003), in reality, the available evidence for age differences is sparse (West, 1999; West & Baylis, 1998) Moreover, aspects of the original experimental task make it difficult to compare with a number of other studies that looked at list level manipulations (Logan et al., 1984; Tzelgov et al., 1992). Specifically, West and Baylis (1998) used a manual version of the Stroop task, which relative to verbal response may lead to an inflation of age-differences (Nebes, 1978; Virzi & Egeth, 1985). In addition, overall response times were sufficiently long (over 1600 ms in some cases) to suggest insufficient practice with the arbitrary color to response button mapping.

Method

Participants

Thirty-four participants were recruited from the Georgia Institute of Technology undergraduate population and received course credit for their participation. Twenty-four healthy older adults were recruited to participate from the Atlanta metropolitan area and received $10 per hour of their participation. All participants provided demographic information and were tested on both the WAIS-Verbal and Digit-Symbol tasks. Participant characteristics are presented in Table 1.

Table 1

Participant characteristics in Experiment 1

	Younger Adults		Older Adults	
Variable	M	(SD)	M	(SD)
Age (in years)	19	(1.41)	68	(4.32)
Education (in years)	13	(1.28)	15	(1.81)
WAIS-Vocabulary[1]	45	(8.86)	52	(6.92)
Digit-Symbol	92	(12.06)	60	(12.21)

[1] WAIS-Vocabulary is the Wechsler Adult Intelligence Scale Vocabulary subtest.

The data from 2 younger adults were excluded due to a high proportion of voice key errors. The data from 4 older adults were excluded; 2 due to voice key errors and 2 due to error rates above 25%. The total sample analyzed included 32 younger adults and 20 older adults.

Apparatus & Materials

Eprime was used on a PC to control the display of stimuli and record RTs with a 1ms resolution. Stimuli were displayed on a 14-in color (VGA) monitor. Subjects responses were recorded by a microphone connected to a Psychology Software Tools Serial Response Box ™.

Words were displayed in San Serif font with each letter subtending 0.17 degrees of visual angle presented against a gray background. There were a total of four words: blue, green, red, and yellow. The four words were presented in each of the four possible colors: blue, green, red, and yellow. Congruent trials were created by displaying each color word in its corresponding color. Incongruent trials were created by displaying each color word in each of the three non-matching colors. There were two-list level conditions; mostly congruent and mostly incongruent. In the mostly congruent condition, participants performed 540 congruent trials and 180 incongruent trials. Out of the 540 congruent trials each of the four words were paired with its corresponding color on 135 trials. Out of the 180 incongruent trials, each of the four words was presented on a total of 45 trials. Within these 45 trials, each word was paired with one of the three non-matching colors. For example, the word RED would be presented in the color red 135 times, the color blue 15 times, the color green 15 times, and the color yellow 15 times. In the mostly incongruent list level condition, participants performed 540 incongruent trials and 180 congruent trials. Out of the 540 incongruent trials, each of the four words was presented on 135 trials. Within these 135 trials, each word was paired with one of the other 3 non-matching colors on a total of 45 trials. For the 180 congruent trials, each of the four words was paired with their corresponding color on 45 trials. In this manipulation, the word RED would be presented in the color blue 45 times, the color green 45 times, the color yellow 45 times and the color red 45 times. The list level manipulation was between subjects with 16 younger adults and 10 older adults assigned to each of the two conditions.

Procedure

Subjects were tested individually while seated next to the experimenter. Each participant performed 20 practice trials in which they saw an equal number of congruent and incongruent trials. The practice trials served to get participants acclimated to the procedure and to adjust the sensitivity of the microphone as needed. The practice trials were followed by 720 trials in the experimental session. The session was broken into 5 blocks of 144 trials each. Each block contained the stimuli in the same proportions in pseudorandom order, with the contingency that no more than five consecutive trials of the same condition could occur. Each participant within each age group saw stimuli in a unique order. Participants were instructed to respond to the color in which the word appeared on the screen while ignoring the word information. Participants were told to respond quickly while maintaining a high degree of accuracy. There was no feedback with regards to RT or accuracy on a given trial. Trials occurred as follows: three fixation crosses were presented in the center of the screen for 500ms followed by a blank screen for 200ms, followed by the presentation of the stimulus. The stimulus remained on the screen until a vocal response was recorded. A constant intertrial interval of 500ms occurred following a response and before the next trial began. Voice key errors were detected and coded by the experimenter along with incorrect responses. The entire experimental session lasted 1 hour.

Results

All statistics reported as significant are based on an alpha level of .05. Responses marked as an error by the experimenter (including incorrect responses and voice key errors), RTs greater than 2500 ms and RTs less than 200 ms were excluded from the analysis. In addition, all RTs falling more than 3 standard deviations from the participant's condition means were also excluded. This resulted in removal of 4.3% of all trials for younger adults and 3.9% of all trials for older adults. Because of the low number of commission errors occurring within the RT trim (2.5% for young and 2.4% for old) analyses on error rates are not reported.

The results are shown in Figure 2. These data were analyzed in a 2 Age (Younger Adults, Older Adults) X 2 List Proportion (Mostly Congruent, Mostly Incongruent) X

Congruency (Congruent, Incongruent) mixed factor analysis of variance (ANOVA) with Age and List Proportion as between-subjects factors and Congruency as a within-subjects factor.

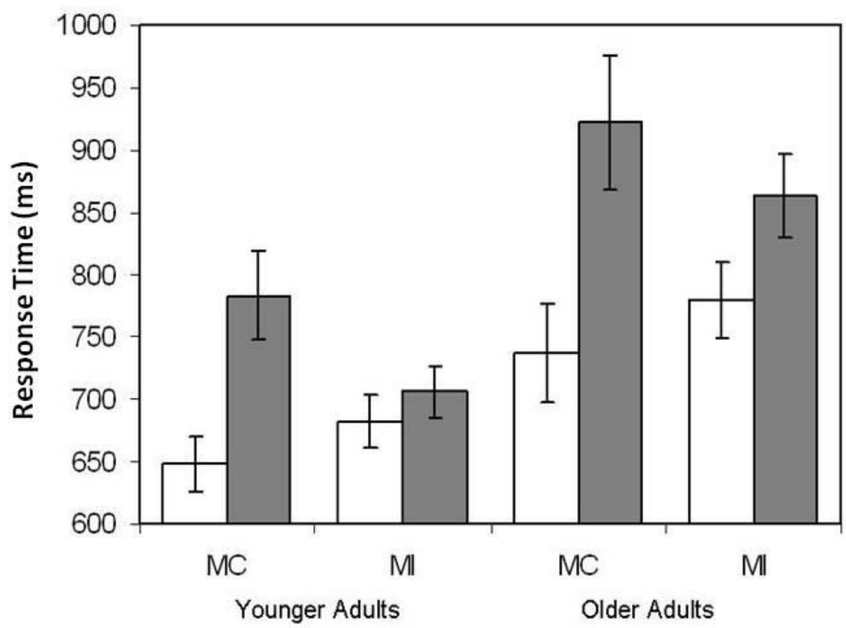

Figure 2. Results of the List Proportion Manipulation in Experiment 1. Here, MC represents the Mostly Congruent List Proportion Manipulation and MI represents the Mostly Incongruent List Proportion Manipulation. Open bars represent congruent trial type and filled bars represent incongruent trial type. Error bars indicate standard error of the mean

Consistent with previous studies on the effects of aging on Stroop performance, there was a significant main effect of Age, *F*(1, 48),= 16.15, *MSE* = 23076, reflecting longer response times for older compared to younger adults. There was also a significant main effect of Congruency *F*(1, 48) = 155.38, *MSE* =295534 suggesting RTs to incongruent trials were slower than RTs to congruent trials for both younger and older adults. There was no main effect of List Proportion $F(1,48) = .304$, $MSE = 23076$ which suggests overall RTs were equal across List Proportions. There was no significant Age X Congruency interaction, $F(1, 48) < 1$, $MSE = 23076$, suggesting that the difference in RTs in a mostly congruent and mostly incongruent block were similar across age. A Congruency X List Proportion interaction was obtained which replicates the findings of decreased congruency effects in the mostly incongruent relative to mostly congruent condition for both younger and older adults, $F(1, 48) = 33.33$, $MSE = 63397$. Finally, the three-way Age X Congruency X List Proportion, $F < 1$ failed to reach significance. Numerically, the modulation of the congruency effect was nearly equal across age groups. Specifically, in younger adults, the reduction in the congruency effect from the mostly congruent to the mostly incongruent conditions was 101 ms. In older adults, the reduction in this effect was 102 ms. The results were also investigated in terms of the RT effects as a proportion of each individual's mean RT (Faust, Balota, Spieler, & Ferraro, 1999). The change in proportion of the congruency effect across ages was highly similar (.15 for young and .13 for old). Taken together, the statistics, numerical, and proportional analyses suggest no difference in the modulation of the congruency effect for younger and older adults.

Discussion

With regards to the empirical replication of West & Baylis (1998), a similar statistical pattern of results was obtained. That is, as the proportion of incongruent trials increases, the congruency effect decreases for both younger and older adults. However, I find no evidence for age-related differences. One possible reason for the discrepant results could be the average ages in the older adult samples. In the original study, the average age of older adults was 74. In the current study, the average age of older adults is 68. It is possible that the age-differences in the original study are not observable until older age. However, there are other important differences between the two studies. In particular, the use of a more traditional verbal response format in the current experiment compared to the manual responses recorded in the original study. Translation accounts of Stroop suggest manual and vocal responses reflect different underlying processes and can be used to obtain different results for the same task (Virzi & Egeth, 1985). Importantly, the differences between manual and Stroop performance can be exacerbated in aging (Nebes, 1978). Thus, it can be argued that the current experiment obtained a more accurate picture of the processes underlying control in aging.

As shown in Experiment 1, a list that contains a high proportion of incongruent (and hence conflict generating) trials will result in smaller congruency effects compared to lists with a low proportion of incongruent trials for both younger and older adults. The conflict adaptation effect links the influence of condition proportion at the list level to the sequential experience of conflict and the resulting feedback that acts to modulate selectivity on subsequent trials. Previous results have suggested that older adults show larger influences of list level condition proportions and this has in turn suggested that older adults are deficient in the maintenance of task set representations that support selectivity and more dependent upon the experience of conflict in reinforcing on going task performance (West & Baylis, 1998). The results of the current experiment call into question the generality of this interpretation. Based on the current results, older adults are not more dependent upon the immediate experience of conflict to reinforce task set representations. Rather, Experiment 1 demonstrates list level effects in both younger and older adults appear to be driven to a similar degree by recent trial history, specifically recent trial condition history[4]. In addition, this is supported by similar modulation of the congruency effect across ages in terms of numerical RT differences and proportional RT differences. In an effort to further investigate the item control account, Experiment 2 examines the extent to which there are other elements within trial history effecting performance on the current trial and whether similar age-related changes to list level manipulations occur.

[4] The direct analysis of sequential effects within a list level manipulation is challenging due to the relatively small number of trials in certain condition repetitions. Though authors have looked at these (see Mayr & Awh, 2009) these analyses may serve to underestimate the effect of previous trial within list level manipulations.

CHAPTER 3

EXPERIMENT 2

Based on the results of Experiment 1, the congruency effect for both younger and older adults is modulated when the proportion of incongruent trials in a list is increased. In an apparent contradiction, existing evidence for the ISPC effect is explained in terms of the modulation of the congruency effect occurring based on current trial information (Bugg, Jacoby, & Toth, 2008; Jacoby et al., 2003). It has previously been argued that the list level manipulation represents a situation in which control on the current trial is modulated by the preceding trial condition (Botvinick et al., 2001). However, if the proportion of conditions is held constant and modulation of the congruency effect is observed, then this is suggestive of control activation based on other experimental factors. In the case of an ISPC manipulation, these factors are history with the current stimulus (Jacoby et al, 2003; Jacoby et al, 1999).

The first aim of Experiment 2 is to examine the extent to which modulation of the congruency effect at the item level is maintained in older adults. Based on the results of Experiment 1, older adult's current trial performance appears to be influenced by previous trial condition to a similar degree as younger adults. If the same mechanism underlies both list level and item level control as has been proposed in the item level control account (Blais et al., 2007), we would expect to see a similar pattern of age-related results as in Experiment 1.

A final aim of Experiment 2 is to improve upon ISPC methodology. It has been pointed out by several researchers that the reported effect is particularly sensitive to stimulus-response repetitions inherent in the experimental design (Schmidt & Besner, 2008; Risko et al., 2008). For example, the breakdown of stimuli in an ISPC manipulation, both the mostly congruent, congruent trials and the mostly incongruent, incongruent trials appear to be faster relative to the other conditions. While this is exactly the effect that drives control related interpretations, those conditions represent exactly the conditions that may be artificially sped up due to an increase in simple stimulus-response repetitions (Mayr, et al., 2003). To date there are no reported data from studies attempting to alleviate this issue. In the current study, modifications were made to the original design by adding two additional colors and color words and adjusting the color-word pairings. This manipulation attempts to dilute repetition effects embedded in this type of manipulation.

Method

Participants

Twenty-four participants were recruited from the Georgia Institute of Technology undergraduate population and received course credit for their participation. Eighteen healthy older adults were recruited from the Atlanta metropolitan area and received $10 per hour of participation. Participants in Experiment 1 were all excluded from participation in Experiment 2. All participants provided demographic information and were tested on both the WAIS-Verbal and Digit-Symbol tasks. Participant characteristics are presented in Table 2.

Table 2

Participant Characteristics in Experiment 2

Variable	Younger Adults M	(SD)	Older Adults M	(SD)
Age (in years)	19	(1.26)	71	(7.02)
Education (in years)	13	(1.26)	16	(3.18)
WAIS-Vocabulary[1]	47.66	(7.95)	49.15	(6.86)
Digit-Symbol	91.00	(14.4)	73.91	14.57

[1]WAIS-Vocabulary is the Wechsler Adult Intelligence Scale Vocabulary subtest.

Apparatus & Materials

Eprime was used on a PC to control the display of stimuli and record RTs with a 1ms resolution. Stimuli were displayed on a 14-in color (VGA) monitor. Subjects responses were recorded by a microphone connected to a Psychology Software Tools Serial Response Box ™.

Stimuli were displayed in six colors (blue, green, red, yellow, black, and white). Six color words (blue, green, red, yellow, black, and white) were displayed in a San Serif font with each letter subtending 0.17 degree of visual angle. Stimulus lists were created using two color/word triads. For a given participant three of the six words were presented in the mostly congruent condition while the remaining three words were presented in the mostly incongruent condition. Within the mostly congruent condition, a given word was presented as a congruent trial 60 times and as an incongruent trial 20 times. Within those 20 incongruent trials, each color was paired 10 times each with the other members of the word triad. In the mostly incongruent condition, a given word was presented as a congruent trial 20 times and as an incongruent trial as one of the colors from the triad 60 times (for layout of stimuli see Table 3).

Table 3

Example of the distribution of stimuli for a single subject in Experiment 2

Block Type					
Mostly Congruent			Mostly Incongruent		
Word Items	Color	# of Items	Word	Color	# of
Yellow	Yellow	60	Red	Black	60
Blue	Blue	60	Green	Red	60
White	White	60	Black	Green	60
Yellow	Blue	10	Red	Red	20
Yellow	White	10	Green	Green	20
Blue	Yellow	10	Black	Black	20
Blue	White	10			
White	Yellow	10			
White	Blue	10			

There were a total of 480 trials. These 480 trials were divided into 5 blocks of 96 trials. The proportion of trials at the experiment wide level was retained within each of the 5 blocks of 96 trials.

Procedure

Subjects were tested individually while seated next to the experimenter. Participants performed 20 practice trials in which they saw an equal number of congruent and incongruent trials. The practice trials served to get participants acclimated to the procedure and to adjust the sensitivity of the microphone as needed. Practice was followed by 480 trials in the experimental session. Participants were instructed to respond to the color of the word appearing on the screen while ignoring the word. Participants were told to respond quickly while maintaining a high degree of accuracy. There was no feedback with regards to RT or accuracy on a given trial. Trials occurred as follows: three fixation crosses were presented in the center of the screen for 500 ms followed by a blank screen for 200 ms, followed by presentation of the word. The word remained on the screen until a vocal response was made. There was a 500 ms intertrial interval following a response before the next trial began. Voice key errors were detected and coded by the experimenter along with error responses. The entire experimental session lasted 1 hour.

Results

All statistics reported as significant are based on an alpha level of .05. Data were excluded using the same criteria as in Experiment 1. This resulted in removal of 4.1% of all trials for younger adults and 4.4% of all trials for older adults. Because of the low number of commission errors occurring within the RT trim (2.4% for young and 1.3% for old) analyses on error rates are not reported.

The results are shown in Figure 3. The data were analyzed in a 2 Age (Younger, Older adults) X Item Proportion (Mostly Congruent, Mostly Incongruent) X 2 Congruency (Congruent, Incongruent) mixed factor ANOVA with Age as a between subjects factor and Item Proportion and Congruency as within-subjects factors. As found in Experiment 1, there was a significant main effect of Age, $F(1, 40) = 12.74$, $MSE = 55126$ reflecting longer RTs for older adults compared to younger adults. There was also a significant main effect of Congruency $F(1, 40) = 302.76$, MSE =610872 suggesting RTs to incongruent trials were slower than RTs to congruent trials for both younger and older adults.

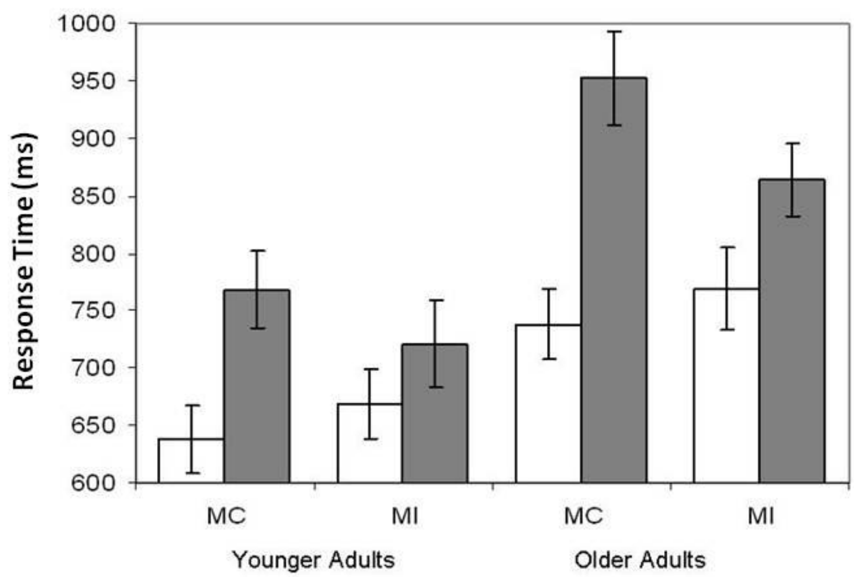

Figure 3. Results of the Item Proportion manipulation in Experiment 2. Here, MC represents the Mostly Congruent List Proportion Manipulation and MI represents the Mostly Incongruent Item Proportion Manipulation. Open bars represent congruent trial type and filled bars represent incongruent trial type. Error bars indicate standard error of the mean.

There was a significant Age X Congruency interaction, $F(1, 40) = 20.07$, $MSE = 40501$ reflecting the greater congruency effect overall for older adults (M=134) compared to younger adults (M=85). Importantly, there was a significant Congruency X Item Proportion interaction $F(1, 40) = 90.22$, MSE=97997 which reflects a reduction in the congruency effect in the mostly incongruent item level proportion compared to the mostly congruent item level proportion replicating previous ISPC results (Jacoby, et al., 2003; Jacoby et al., 1999). Finally, in contrast to Experiment 1, the three-way Age X Congruency X Item Proportion interaction, $F(1, 40) = 4.09$, $MSE = 1086$ (see Figure 3) was obtained. This suggests changes in the congruency effect based on the item proportion were larger in older relative to younger adults. Numerically, consistent with the significant three-way interaction, the modulation of the congruency effect was greater for older (M = 119 ms) compared to younger adults (M = 78). However, in terms of the effects as proportions of each individual's RT (Faust et al., 1999), both younger and older adults showed similar modulation of the congruency effect (.12 for younger adults and .14 for older adults). The lack of a finding of large differences in proportional RT is not consistent with statistical or numerical results and may suggest caution when interpreting the Age X Congruency X Item Proportion interaction.

Discussion

A reduction of the congruency effect in the mostly incongruent condition was obtained for both younger and older adults. Though this finding is supported by statistical and numerical differences, the lack of differences in modulation of the effect in proportional RTs should be noted. In general, this result offers further support for the ISPC effect in light of the dilution of response repetitions. The results also suggest older adults are able to modulate performance based on specific stimulus information occurring on the current trial, and somewhat surprisingly, even demonstrate statistically and numerically larger modulations from the mostly congruent to mostly incongruent item type. This result is counter to predictions of older adults demonstrating less of an effect of item-specific associations due to difficulties in associative learning as well as inconsistent with item level theories of control that argue similar mechanisms of control underlie both item level and list level effects.

CHAPTER 4

GENERAL DISCUSSION

The current experiments offer evidence for the ability of individuals to modulate performance in response to specific stimulus history. Experiment 1 suggests both younger and older adults are able to modulate performance based on list level context (i.e. mostly congruent versus mostly incongruent list level manipulations) and that this modulation is similar across age groups. The results of Experiment 2 provide additional evidence for the influence of specific items on performance in the absence of a list level manipulation. Within an item specific manipulation, no one condition is any more likely to be preceded by a congruent or incongruent trial. A conflict monitoring account would predict no variation in the congruency effect in an item level manipulation. Therefore, the modulation observed must be due in part to information obtained from the current trial and based on stimulus history. Further, Experiment 2 suggests the ability to modulate performance in response to specific stimulus history is maintained in healthy aging.

Implications for Current Theories of Control

The conflict monitoring explanation of list level manipulations is unable to explain the modulation of performance at the item level. However, an item level control model has been proposed which simulates both item level and list level effects using a single item level mechanism (Blais, et al., 2007). The item level control model contains the same structure as the conflict monitoring model but differs on the specificity of the conflict signal. The conflict signal in the item control model is specific to the word and color dimensions. For example, in the mostly incongruent condition of an item level manipulation, the word BLUE presented in green on trial *n-1* would lead to tightening of control only for a stimulus containing the word BLUE or color green on trial *n*. In the absence of word or color repetitions, no modulation of control would be predicted (Blais et al., 2007).

The item control account encounters two difficulties based on the results of the current set of experiments. The first issue comes from the age-related differences in the modulation of control in the item level compared to list level manipulation. Though the current experiments were not set up to perfectly equate the color/word contingencies across experiments, if it is the case that the same mechanism underlies both item level and list level manipulation, then the age-related effects should remain constant across both experiments. Comparison of the results from Experiment 1 and Experiment 2 suggest this is not the case. Rather, younger and older adults demonstrate statistically and numerically similar modulations of the congruency effect at the list level (Experiment 1), but statistically and numerically different modulation of the congruency effect at the item level (Experiment 2).

A related difficulty for the item control account to reconcile is the performance of older adults in the item-level manipulation. This account presumes a control based on associative learning throughout the length of the experiment. For example, the conflict signal is stimulus specific because participants have learned to associate the word dimension with a given color dimension. In the case of Experiment 2, older adults actually demonstrate greater modulation of performance from the mostly congruent to the mostly incongruent item level. In sum, despite evidence or conflict adaptation mechanisms leading to list level effects (Botvinick et al., 2001), evidence for associative mechanisms leading to ISPC effects (Jacoby et al., 2003; Jacoby et al., 1999) and the suggestion that list level and item level manipulations may be driven by a single mechanism (Blais et al., 2007), no one account appears to be able to satisfactorily explain the variety of results.

The inability of current theories of control to explain the results of list level and item level manipulations suggests that there may be an overemphasis on "conflict" in models of control in the absence of what conflict signals to an organism. The interference tasks that are commonly used to demonstrate modulations of control involve stimuli with multiple dimensions that are assigned to a small number of categorical responses. While the experimenter may label only one dimension (color, central letter) the relevant dimension, common experimental designs create situations where the "irrelevant" dimension carries useful information about the likely response. For example, in a typical Stroop design, congruent and incongruent trials will appear in equal proportions. However, the manner in which stimuli are counterbalanced actually leads to unintended differences between the marginal and conditional probability of the correct response. In a three color task it is typically the case that the marginal probability of the response being RED is equal to .33, however, the conditional probability, that is the probability of the response being RED given that the word is red, is equal to .5. The difference in probabilities serves as information regarding processing that may be utilized by participants in the absence of their explicit knowledge, and there is evidence that knowledge about the correlational structure of the stimuli appears to be automatically learned by participants (Dishon-Berkovits, & Algom, 2000; Miller, 1987).

Manipulations of the proportion of congruent and incongruent stimuli are direct manipulations of the predictive ability of this irrelevant dimension. For example, in a similar case for the mostly congruent list level the marginal is equal to .33 while the conditional is equal to .75. In contrast, in the mostly incongruent list level, the marginal probability and conditional probability are equal to .33. Framed in this way, the presence of conflict is also a signal that the predictive ability of the irrelevant dimension has at least on this instance, led one toward the wrong response. More generally, situations of high conflict are those situations where potentially large adjustments should be made in response to the weighting of different dimensions. In sum, further attention will need to be paid to exactly what stimulus information is processed throughout the length of an experiment.

Another interesting recent account regarding the usefulness of the conflict monitoring signal suggests conflict serves as a teaching signal in avoidance learning (Botvinick, 2007). For example, the ACC, specifically the Dorsal Anterior Cingulate Cortex (dACC) increases in activation when the outcome of a trial is inconsistent with a learned reward (Bush, et al., 2002). In this case, the occurrence of conflict is used as an event that is to be avoided. In this interpretation, ACC activation serves to alert the system to avoid using processing strategies that have previously led to the signal (Botvinick, 2007). The interesting aspect of this theory in regards to the current paper is that it suggests the conflict signal is a mechanism of learning. This highlights the increased emphasis of current research on the richness of information carried by a conflict signal.

Cognitive Control and Aging

In addition to the interesting implications the current set of experiments has for existing control theories, the results of the experiment are also interesting in terms of the age-related outcomes. In Experiment 1, younger and older adults were able to modulate performance based on condition history in a similar manner. These results replicated the statistical results of a previous study (West & Baylis, 1998), however may lead to a different interpretation. The authors there argue, in light of numerical differences between the modulation of the performance for older adults relative to younger adults, in conjunction with EEG results that older adults were more influenced by trial condition than young. In contrast, the current study found no numerical differences in the modulation of the congruency effect between younger and older adults.

The results of Experiment 2 clearly show that older adults are able to modulate their performance based on a variety of information from preceding trials. Both the mere existence of the item level effect in aging and the statistically larger effect in aging is surprising in light of associative learning accounts. Though older adults typically perform worse than younger adults on associative learning tasks (Spieler & Balota, 1996), it appears they are able to use color and word associations in order to influence performance.

All of the results for older adults should be viewed in light of research that older adults are exactly the individuals who are often argued to have decrements in control processing (Braver & Barch, 2002; Spieler et al., 1996; West, 1996). One interesting prediction could be the adaptive use of information increases in older age. That is, in tasks older adults have difficulty with, they will seek out and use all the information available to them on the current trial (Spieler, Mayr, & LaGrone, 2006). It has even been shown that by providing older adults with enough context information, older adults are able to perform as well as younger adults (Madden, Whiting, & Cabeza, 2004). Counter intuitively, because older adults typically demonstrate larger congruency effects compared to young, it is possible this deficiency in inhibition leads to better learning of color/word associations. That is, if older adults are not able to inhibit irrelevant word information, word information enters the system allowing for associations to be learned.

Conclusion

The results of the current study are important for 3 reasons. First, both younger and older adults are able to modulate control in response to list level and item level manipulations. Second, item level and list level manipulations do not have the same underlying mechanism, reflected in the results of different age-effects between Experiment 1 and Experiment 2. Finally, older adults were able to modulate control based on item level manipulations, which suggests an adaptive control mechanism that may be implemented by older adults in tasks of selective attention. An intriguing thought is as our understanding of performance modulation in terms of specific stimulus information increases and the reliance on a non-specific control signal decreases, this may lead to important advancements regarding the refinement the often nebulous construct of cognitive control.

REFERENCES

Blais, C., Robidoux, S., Risko, E. F., & Besner, D. (2007). Item-specific adaptation and the conflict monitoring hypothesis: A computational model. *Psychological Review, 114*, 1076-1086.

Botvinick, M. M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognitive, Affective, & Behavioral Neuroscience, 7,* 356-366.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624-652.

Botvinick, M. M., Braver, T. S., Yeung, N., Ullsperger, M., Carter, C. S., & Cohen, J. D. (2004). Conflict monitoring: Computational and empirical studies. In M. I. Posner (Ed.), Cognitive neuroscience of attention (pp. 91-102). New York: Guilford Press.

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience and Biobehavioral Reviews, 26,* 809-817.

Braver, T. S., Barch, D. M., Keys. B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., et al. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General, 130,* 746-763.

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science, 280,* 747-749.

Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology, 40,* 343-367.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account for the Stroop effect. *Psychological Review, 97,* 332-361.

Cohn, N. B., Dustman, R. E., & Bradford, D. C. (1984). Age-related decrements in Stroop color test performance. *Journal of Clinical Psychology*, 40, 1244-1250.

Crump, M. J. C., Gong, Z., & Milliken, B. (2006). The context-specific proportion congruent Stroop effect: Location as a contextual cue. *Psychonomic Bulletin & Review, 13*, 316-321.

Dehaene, S., Posner, M I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science, 5,* 303-305.

Dishon-Berkovits, M., & Algom, D. (2000). The Stroop effect: It is not the robust phenomenon that you thought it to be. *Memory & Cognition, 28*, 1437-1449.

Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective, & Behavioral Neuroscience, 7*, 380-390.

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience, 8,* 1784-1790.

Eriksen, B. A. & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception and Psychophysics*, *16*, 143-149.

Faust, M. E., Balota, D. A., & Spieler, D. H. (1999). Individual differences in information processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125*, 777-799.

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 121*, 480-506.

Hedden, T. & Gabrieli, J. D. E. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5*, 87-96.

Holroyd, C. B., Nieuwenhuis, S., Yeung, N., Nystrom, L., Mars, R. B., Coles, M.G., et al. (2004). Dorsal anterior cingulate cortex shows fMRI response to internal and external signals. *Nature Neuroscience, 7*, 497-498.

Hommel, B., Proctor, R. W., & Vu, K.-P. L. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research*, *68*, 1-17.

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review, 10*, 638-644.

Jacoby, L. L., McElree, B., & Trainham, T. N. (1999). Automatic influences as accessibility bias in memory and Stroop-like tasks: Toward a formal model. In D. Gopher and A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance.Interaction of theory and application* (pp.. 461-486). Cambridge, MA: MIT Press.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*, 47-70.

Kerns, J. G., Cohen, J. D., MacDonald III, A. W., Cho, R. Y., Stenger, V. A. & Carter, C. S. (2004). Anterior cingulated conflict monitoring and adjustments in control. *Science, 303*, 1023-1026.

Kimberg, D. Y., & Farah, M. J. (1993). A unified account of cognitive impairments following frontal-lobe damage: The role of working-memory in complex, organized behavior. *Journal of Experimental Psychology: General, 122*, 411-428.

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 219-234.

Logan, G. D. & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory & Cognition, 7*, 166-174.

Logan, G. D. & Zbrodoff, N. J., & Williamson, J. (1984). Strategies in the color-word Stroop task. *Bulletin of the Psychonomic Society, 22*, 135-138.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163-203.

Madden, D. J., Whiting, W. L., Cabeza, R., & Huettel, S. A. (2004). Age-related preservation of top-down attentional guidance during visual search. *Psychology and Aging, 19*, 304-309.

Mayr, U., & Awh, E. (2009). The elusive link between conflict and conflict adaptation. *Psychological Research, 73*, 794-802.

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience, 6*, 450-452.

Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review, 110*, 422-471.

Milham, M. P., Erickson, E. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional control in the aging brain: Insights from an fMRI study of the Stroop task. *Brain and Cognition, 49*, 277-296.

Miller, E. K. & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Miller, J. (1987). Priming is not necessary for selective attention failures: Semantic effects of unattended, unprimed letters. *Perception & Psychophysics, 41*, 419-434.

Miltner, W. H. R., Lemke, U., Weiss, T., Holroyd, C., Scheffers, M. K., & Coles, M. G. H. (2003). Implementation of error-processing in the human anterior cingulate cortex: A source analysis of the magnetic equivalent of the error-related negativity. *Biological Psychology, 64*, 157-166.

Moritz, S., Birkner, C., Kloss, M., Jahn, H., Hand, I, Haasen, C et al. (2002). Executive functioning in obsessive-compulsive disorder, unipolar depression, and schizophrenia. *Archives of Clinical Neuropsychology, 17*, 477-483.

Mutter, S. A., Naylor, J. C., & Patterson (2005). The effects of age and task context on Stroop task performance. *Memory & Cognition, 33*, 514-530.

Nebes, R. D. (1978). Vocal versus manual response as a determinant of age difference in simple reaction-time. *Journals of Gerontology, 33*, 884-889.

Nessler, D., Friedman, D., Johnson Jr., R., Bersick, M. (2007). ERPs suggest that age affects cognitive control but not response conflict detection. *Neurobiology of Aging, 28*, 1769-1782.

Nieuwenhuis, S., Stins, J. F., Posthuma, D., Polderman, T. J. C., Boomsma, D. I., & de Geus, E. J. (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory & Cognition, 34*, 1260-1272.

Notebaert, W., Gevers, W., Verbruggen, F., & Liefooghe, B. (2006). Top-down and bottom-up sequential modulations of congruency effects. *Psychonomic Bulletin & Review, 13*, 112-117.

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cerebral Cortex, 18*, 1010-1028.

Peterson, B. S., Skudlarski, P., Gatenby, J. C., Zhang, H., Anderson, A. W., & Gore, J. C. (1999). An fMRI study of Stroop word-color interference: Evidence for cingulate subregions subserving multiple distributed attentional systems. *Biological Psychology, 45*, 1237-1258.

Raz, N. (2005). The aging brain observed in vivo: Differential changes and their modifiers. In R. Cabeza, L. Nyberg, & D. Park (Eds.). Cognitive neuroscience of aging (pp 19-57). Oxford: Oxford University Press.

Risko, E. F., Blais, C., Stoltz, J. A., & Besner, D. (2008). Nonstrategic contributions to putatively strategic effects in selective attention tasks. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 1044-1052.

Schmidt, J. R., & Besner, D. (2008). The Stroop effect: Why proportion congruent has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 514-523.

Spieler, D. H., & Balota, D. A. (1996). Characteristics of associative learning in younger and older adults: Evidence from an episodic priming paradigm. *Psychology & Aging, 11*, 607-620.

Spieler, D. H., Balota, D. A. & Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 461-479.

Spieler, D. H., Mayr, U., LaGrone, S. (2006). Outsourcing of cognitive control to the environment: Adult age differences in the use of task cues. *Psychonomic Bulletin & Review, 13*, 787-793.

Tzelgov, J., Henik, A., Berger, J. (1992). Controlling Stroop effects by manipulating expectations for color words. *Memory & Cognition, 20*, 727-735.

Ullsperger, M., Bylsma, L. M., & Botvinick, M. M. (2005). The conflict adaptation effect: It's not just priming. *Affective & Behavioral Neuroscience, 5*, 467-472.

Vanderhasslet, M.-A., De Raedt, R., & Baeken, C. (2009). Dorsolateral prefrontal cortex and Stroop performance: Tackling the lateralization. *Psychonomic Bulletin & Review, 16*, 609-612.

Verhaeghen, P. & De Meersman, L. (1998). Aging and the Stroop effect: A meta-analysis. *Psychology and Aging, 13*, 120-126.

Virzi, R. A., & Egeth, H. E. (1985). Toward a translational model of Stroop interference. *Memory & Cognition, 13,* 304-319.

Wendt, M., Kluwe, R. H., & Peters, A. (2006). Sequential modulations of interference evoked by processing task-irrelevant stimulus features. *Journal of Experimental Psychology:Human Perception and Performance, 32,* 644-667.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*, 272-292.

West, R. (1999). Age differences in lapses of intention in the Stroop task. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 54*, P34-P43.

West, R., & Alain, C. (2000). Age-related decline in inhibitory control contributes to the increased Stroop effect observed in older adults. *Psychophysiology, 37*, 179-189.

West, R., & Baylis, G. C. (1998). Effects of increased response dominance and contextual disintegration on the Stroop interference effect in older adults. *Psychology & Aging, 13*, 206-217.

West, R. L., & Moore, K. (2005). Adjustments of cognitive control in younger and older adults. *Cortex, 41*, 570-581.